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THE DESIGN AND OPERATION OF A SIMPLE LOW-SPEED FLUTTER-SUPPRESSION MODEL

A. GOLDMAN

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THE DESIGN AND OPERATION OF A SIMPLE LOW-SPEED FLUTTER-SUPPRESSION MODEL

by

A. GOLDMAN

SUMMARY

A dynamic model has been developed for use in a small low-speed wind tunnel. A feedback system has been used to drive a control surface in order to suppress flutter. Details of the model and the results of preliminary tests are presented.

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1. INTRODUCTION

As a preliminary investigation, prior to a detailed mathematical analysis, a small dynamic flutter model has been designed and tested, in order to explore the problems of instrumentation and control. The wind tunnel working section of 460 millimetres x 460 millimetres, and a maximum speed of 19.5 metres per second were the major constraints in the model design.

The model has a driven control surface and three built-in accelerometers. The stiffness and mass distribution were adjusted to cause a wing torsion-bending coupled flutter, within the tunnel speed range. The electronic control system provided a feedback signal to the control surface which could be adjusted in gain and phase.

2. DESCRIPTION OF MODEL

The wing section has a span of 205 millimetres and chord 163 millimetres and a control surface of span 95 millimetres and chord 54 millimetres. The wing itself can be regarded as inflexible for the purpose of this project. The flexibility required was introduced by mounting the wing on a piece of spring steel, which provided low frequency pitch and bending modes. The mass distribution was adjusted by moving a mass on a rod attached to the trailing edge of the wing.

In order to obtain a flutter model at speeds below 19 metres per second it was necessary to have the torsional axis well behind the centre of pressure, and to have the torsional and bending frequencies below 6 hertz and closely spaced.

Fig. 1 shows the general arrangement of the model on its support, and Fig. 2 is a photograph of the model mounted on the removable wind-tunnel window.

Because the whole wing moved as a rigid body, the wing root could not be fixed, and the control surface actuator had to form part of the dynamic system. A 6-volt, 5-watt motor was mounted at the wing-root and direct-coupled to the control-surface shaft. Rotational stops were fitted to prevent oscillations of greater than ± 10 degrees. The motor was tested and found to follow a sinusoidal current input quite accurately up to 30 hertz.

3. DESCRIPTION OF INSTRUMENTATION

To monitor the motion of the wing, three accelerometers, Endevco type 2250, are mounted within the wing. The locations of these are shown on Fig. 1 and are designated M, L and C as abbreviations for Mid-chord, Leading-edge, and Control-surface.

The accelerometer output to be used for control purposes is passed through two stages of amplification and filtering before being fed into a power amplifier which controls the actuator. The filters have a 1 hertz high-pass and 50 hertz low-pass characteristic and, when connected in series, have a phase characteristic as shown in Fig. 3. The amplification stages provide an overall gain of 1000.

This amplified signal, as well as controlling the power amplifier, is also connected, via a 10 hertz low-pass filter, to the input of a random decrement analyser. This device, designed at A.R.L. and based on principles set out in Ref. 1, produces an averaged time history which indicates the impulse response of the structure, and hence provides an indication of the damping of the mode being examined.

An instantaneous spectrum of the response of the wing is obtained by connecting the output of the accelerometers to a dual-channel spectrum analyser.

4. TEST PROCEDURES

The tunnel was operated at speeds from 14 to 19.5 metres per second with measurements of damping being made at each speed. Power spectra were then obtained from locations M and L at 19 metres per second without feedback control, and with feedback from each of the two accelerometers in turn. Measurements of damping were also made at 18 and 19.5 metres per second with feedback control operating.

As a test of the reaction time of the system, a crude store was attached to the wing in such a way that the wing with store was stable at a speed of 18 metres per second. The store was released when the feedback control was on and also when it was off. The system was observed to maintain minimum vibration levels before release and immediately afterwards. Without feedback control, the vibrations rapidly became quite violent.

Because this work was a preliminary task prior to mathematically modelling the structure for digital control purposes, it was necessary to measure several physical parameters of the model. These were the mass, location of centre of gravity, moments of inertia about both axes of rotation, and the location of these axes of rotation for each of the two modes of vibration.

Moments of inertia were measured using the parallel axis theorem, and treating the model as a pendulum pivoted about two separate axes. The locations of the axes of rotation, or nodal lines, for each mode were measured using a travelling accelerometer located successively at each corner of the model. The transfer function was obtained using the built-in accelerometer at location L as a reference. As the model can be regarded as rigid, the nodal line location was obtained by straight-line extrapolation and interpolation.

5. RESULTS

From Figs. 4 to 9 it can be seen that damping has gone from greater than 10 percent of critical at 14 metres per second to approximately 0.5 percent of critical at 19.5 metres per second. Table 1 lists the estimates of damping made at each speed and at two speeds with feedback control applied. The damping was estimated using the relationship between successive amplitudes over the first two cycles of oscillation.

The effect of feedback control may be seen in Figs. 10 and 11 which show the random decrement signatures with the control activated. These should be compared with Figs. 7 and 9 which show the respective uncontrolled signatures. The damping has increased by approximately 7.5 percent in both cases.

The results of averaging in the frequency domain are presented in Figs. 12 to 17. These figures were produced using 8 ensembles and a 128 point display. The resolution is 0.25 hertz. Figs. 12 and 13 show the response at the wing tip, "LOC-L" being leading edge location L on Fig. 1, and "LOC-M" being mid-chord location M on the same figure. It will be seen that the predominant frequency is approximately 6.5 hertz. Figs. 14 and 15 show the averaged response at both locations when controlled by feedback from location "M". The frequency content at 6.5 hertz has been eliminated and the overall vibration level greatly reduced. Figs. 16 and 17 show the effect of feedback from location "L" being applied to the control system. The vibration levels have been increased and the predominant frequency lowered to between 6.0 and 6.25 hertz. A transfer function of the two frequency spectra revealed that there was approximately 90 degrees phase displacement between the two displacements at the predominant frequency.

The results of the physical dimension measurements are presented in Table 2. From these measurements, the following moments of inertia were calculated:-

About XX axis   :   0.00182 Kg - m^2

About YY axis   0.0036 Kg - m^2

About X'X' axis :   0.00159 Kg - m^2
(product of
inertia)

6.   CONCLUSIONS AND DISCUSSION

The work to date has demonstrated that it is possible
to operate a dynamic model of small dimensions in a small low-speed
wind-tunnel, successfully monitor vibrations, and use these
vibration signals to operate a feedback control.

The preliminary tests were completed in a relatively
short period of time using general laboratory equipment.

The problems that exist are the poor control of
phase using a variable analogue filter, and the amount of noise
being transmitted to the actuator. The filter characteristics are
generally such that any significant change in phase at one frequency
is likely to have an adverse effect on other frequencies. The noise
transmission is brought about by the high gain in the feedback system.
This is necessary because of the low output of the accelerometers
(5 millivolts per "g") and the use of a 6-volt actuator.

The next stage of the project will be to utilize more
sophisticated analogue feedback control systems, prior to the use of
a digital computer and a digital control algorithm.

Similar work has been carried out at NASA Langley
(Ref. 2) using much larger models and a high-speed digital computer.
The present work indicates that flutter suppression can be demonstrated
in a very simple test facility.

REFERENCES

1.   On-line failure detection and damping measurement of
        aerospace structures by random decrement signatures.

        Henry A. Cole Jnr.   -   NASA CR-2205
                                  March 1973

2.   Adaptive Flutter Suppression - Analysis and Test.

        Johnson, E.H.,   -   AGARD-R-703
        Harvey, C.A.,   January 1983.
   Huttsell, L.T., and
        Farmer, M.G.

TABLE 1

Damping vs. Air-speed

Air speed metres per second	Damping (% critical) No control	Feedback control
14	> 10	–
16	9.6	–
17	3.7	–
18	2.4	9.8
19	0.8	–
19.5	0.5	8

TABLE 2

Physical measurements

Wing span	205 mm
Wing chord	163 mm
Control surface span	95 mm
Control surface chord	54 mm
Bending mode frequency	4.5 Hz
Pitch mode frequency	6.6 Hz
Pendulum frequency about an axis 35 mm leading XX	1.4 Hz
Pendulum frequency about an axis 30 mm outboard from YY	0.96 Hz
Location of C.G. aft of XX	35 mm
Location of C.G. out from YY	58.5 mm
Total mass	0.349 Kg

Flexure Spring

X L

X M

Model
Support

X C

Control
Surface

Control Surface
Actuator

Control
Surface
Mass-Balance

Tunnel
Wall

Wing Mass
Balance
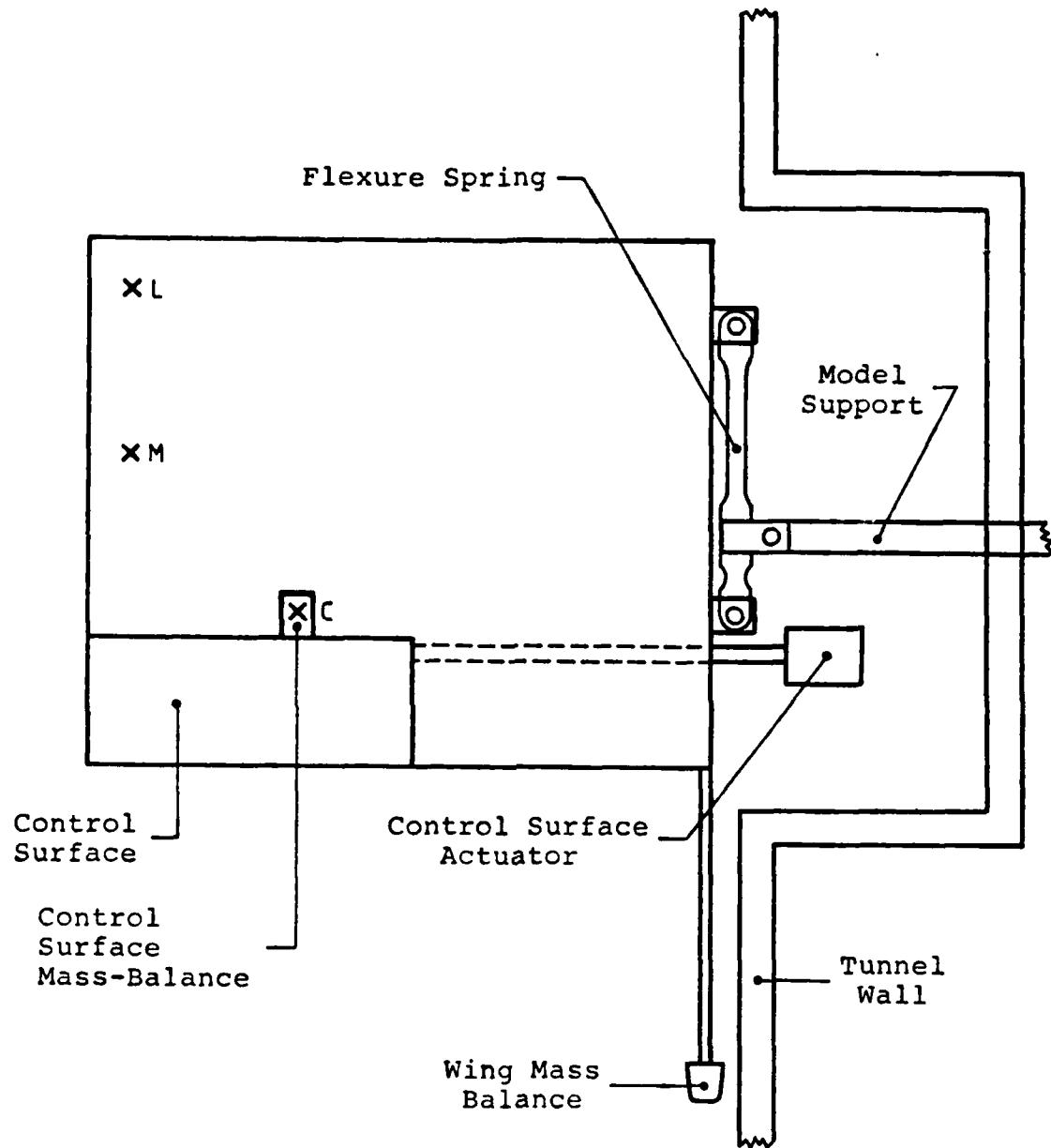
X = Accelerometer
Locations Inside
Wing Structure

FIG. 1(a)   GENERAL LAYOUT OF MODEL
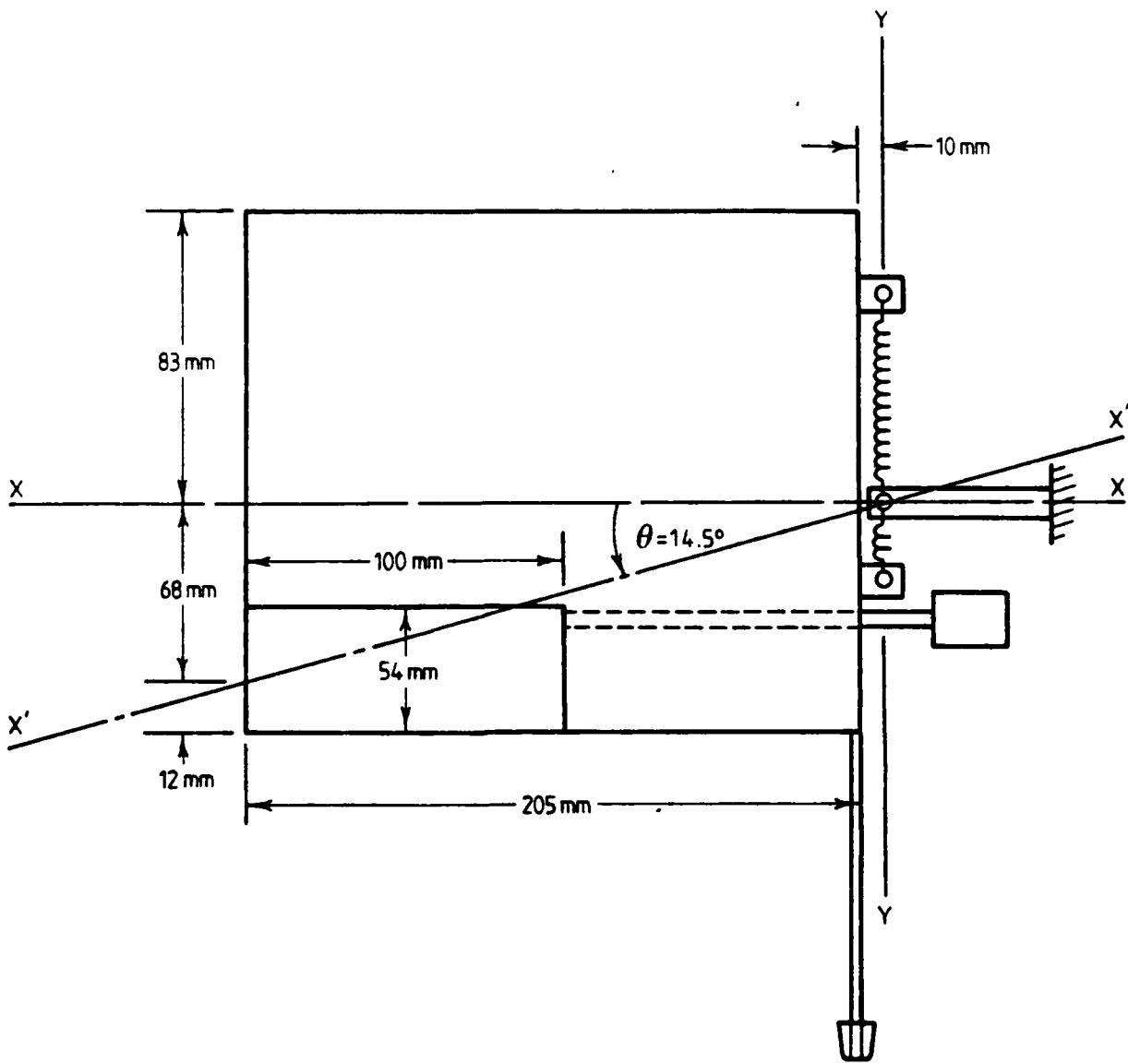
FIG. 1(b)   PLANFORM OF MODEL SHOWING PRINCIPAL DIMENSIONS

Actuator

Flexure
Spring

Main
Support
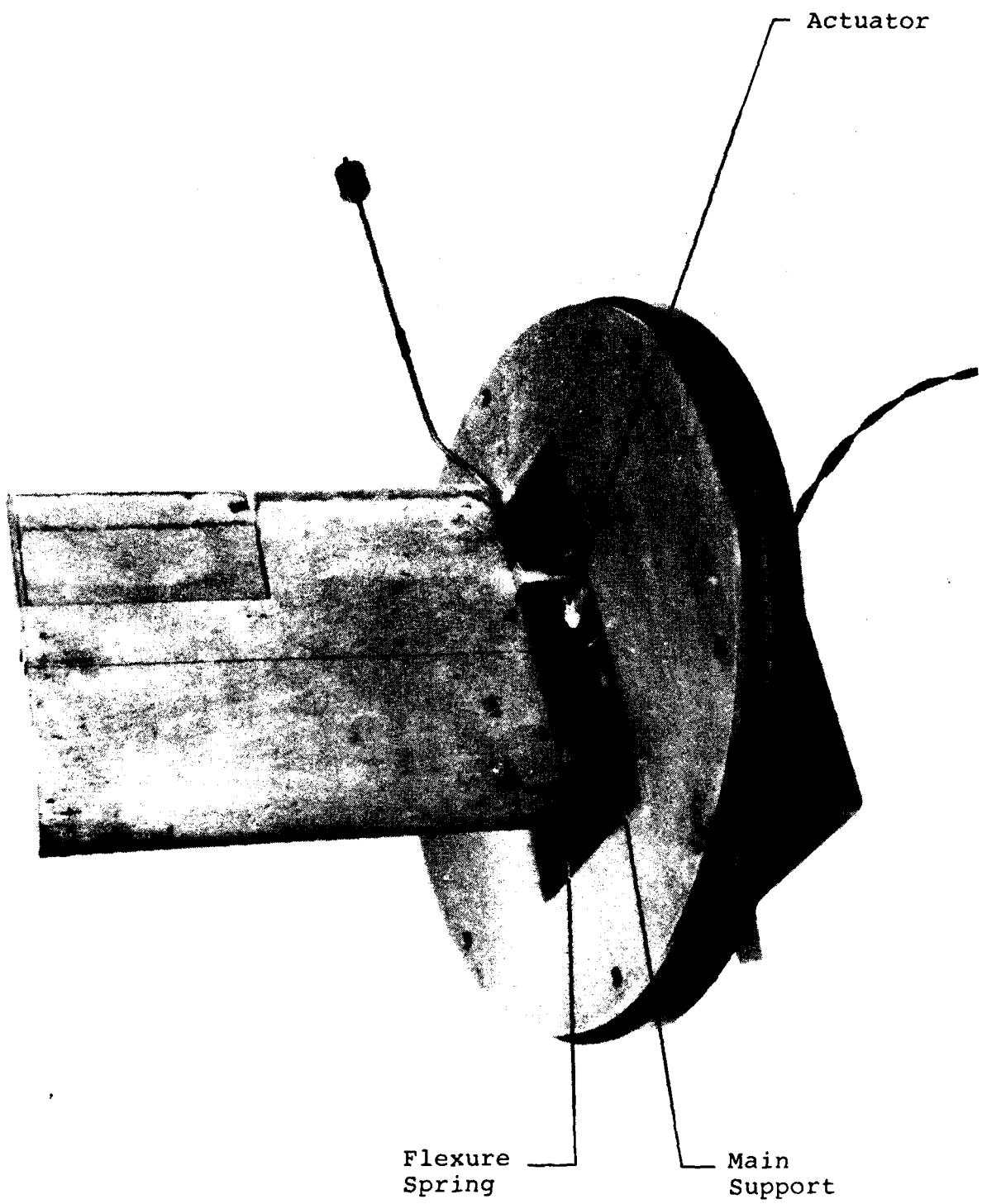
FIG. 2.   MODEL MOUNTED ON REMOVABLE TUNNEL WINDOW
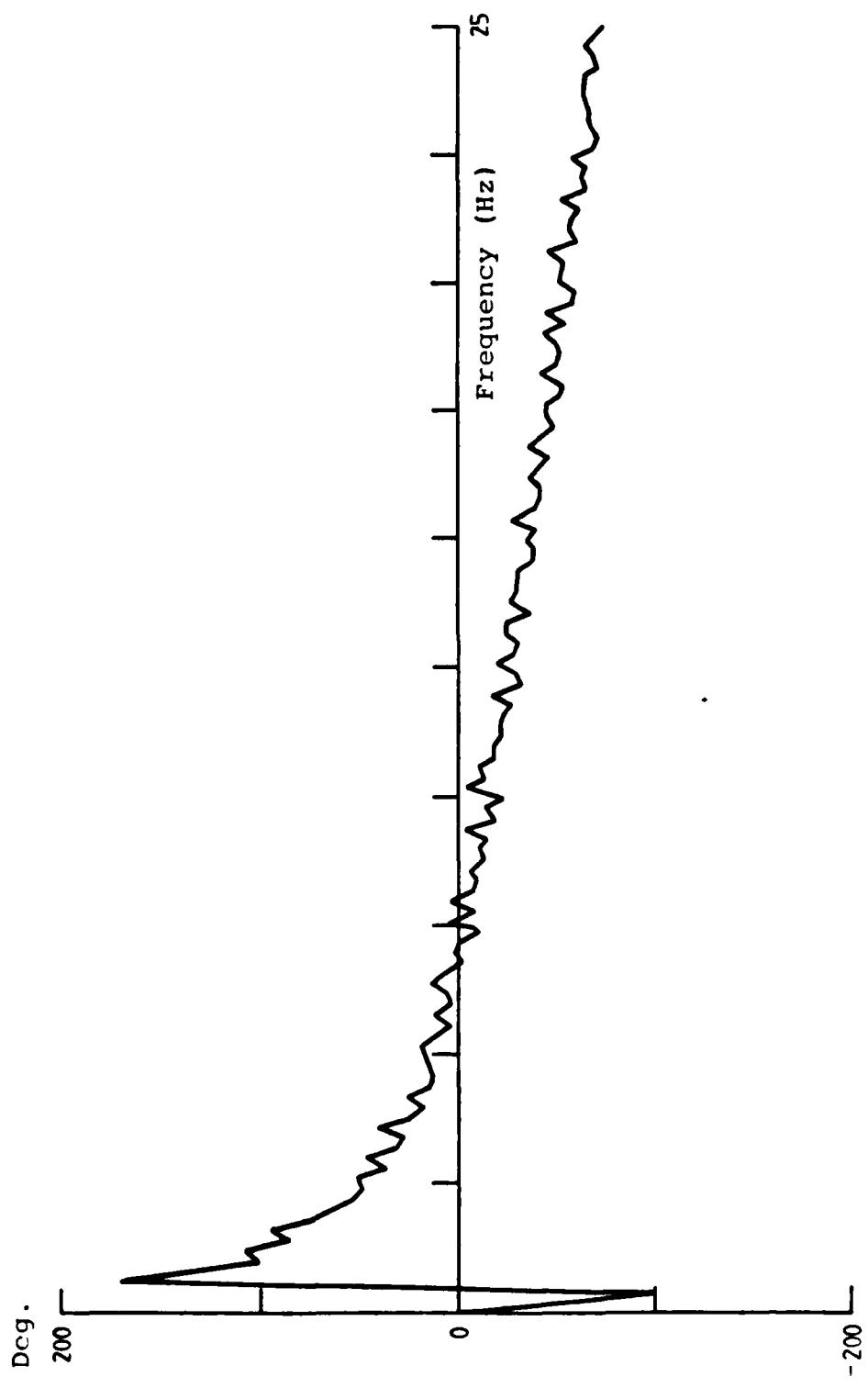
FIG. 3. PHASE DIAG OF AMP/FILT SYSTEM
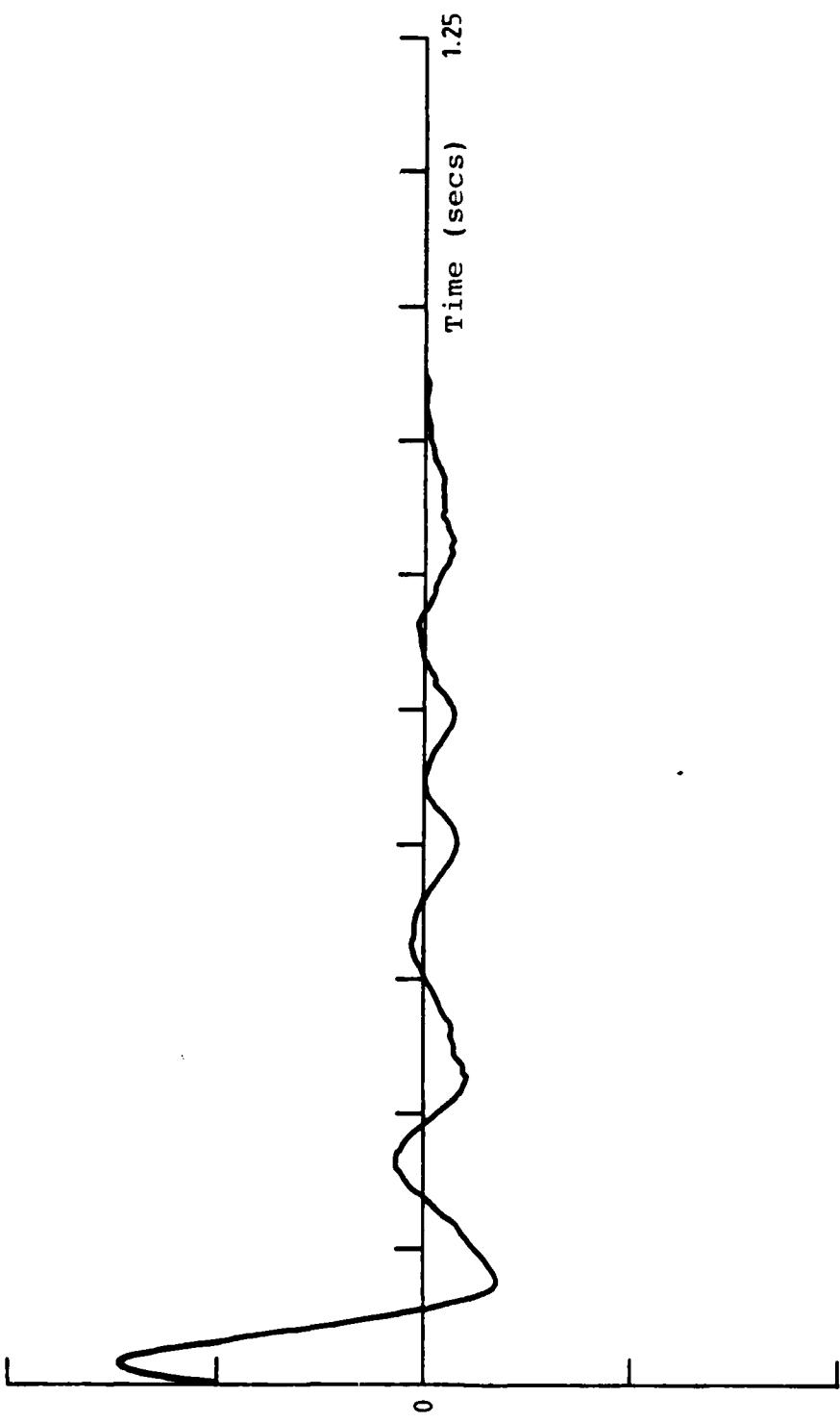
FIG. 4. DAMPING AT 14m/s

Time (secs)

1.25

0
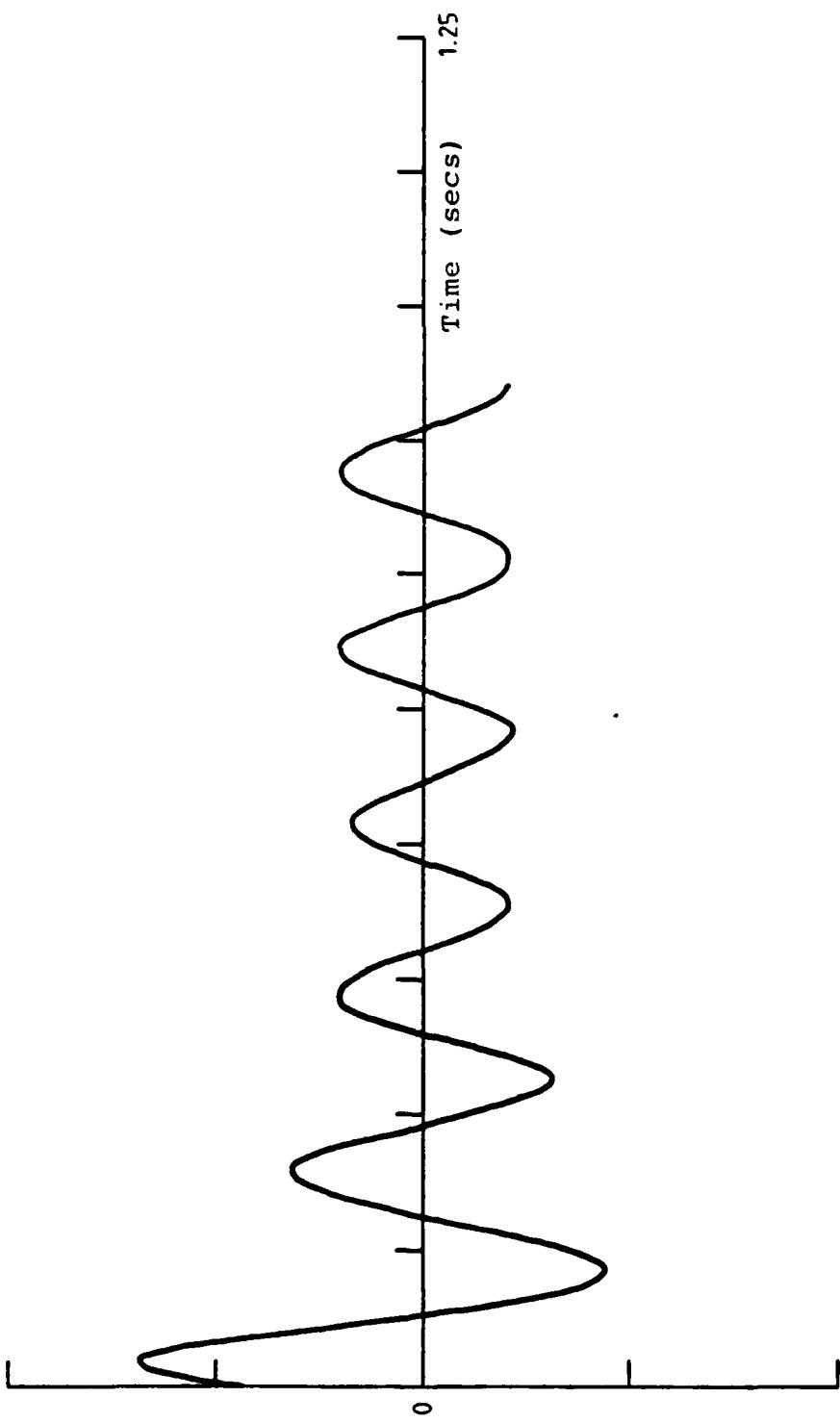
FIG. 5.   DAMPING AT 16m/s

FIG. 6. DAMPING AT 17m/s

Time (secs)

1.25

0
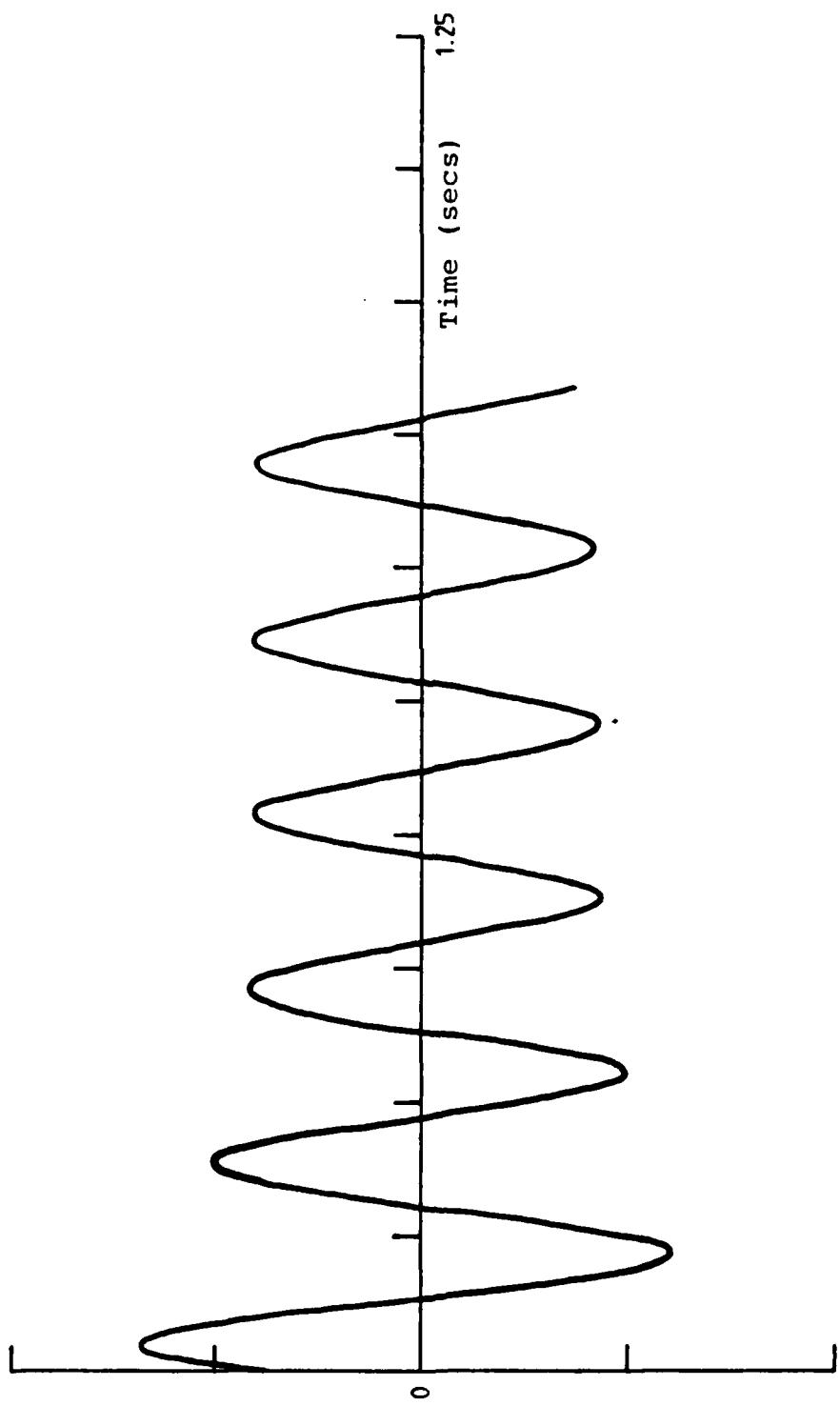
FIG. 7.   DAMPING AT 18m/s

Time (secs)

1.25

0
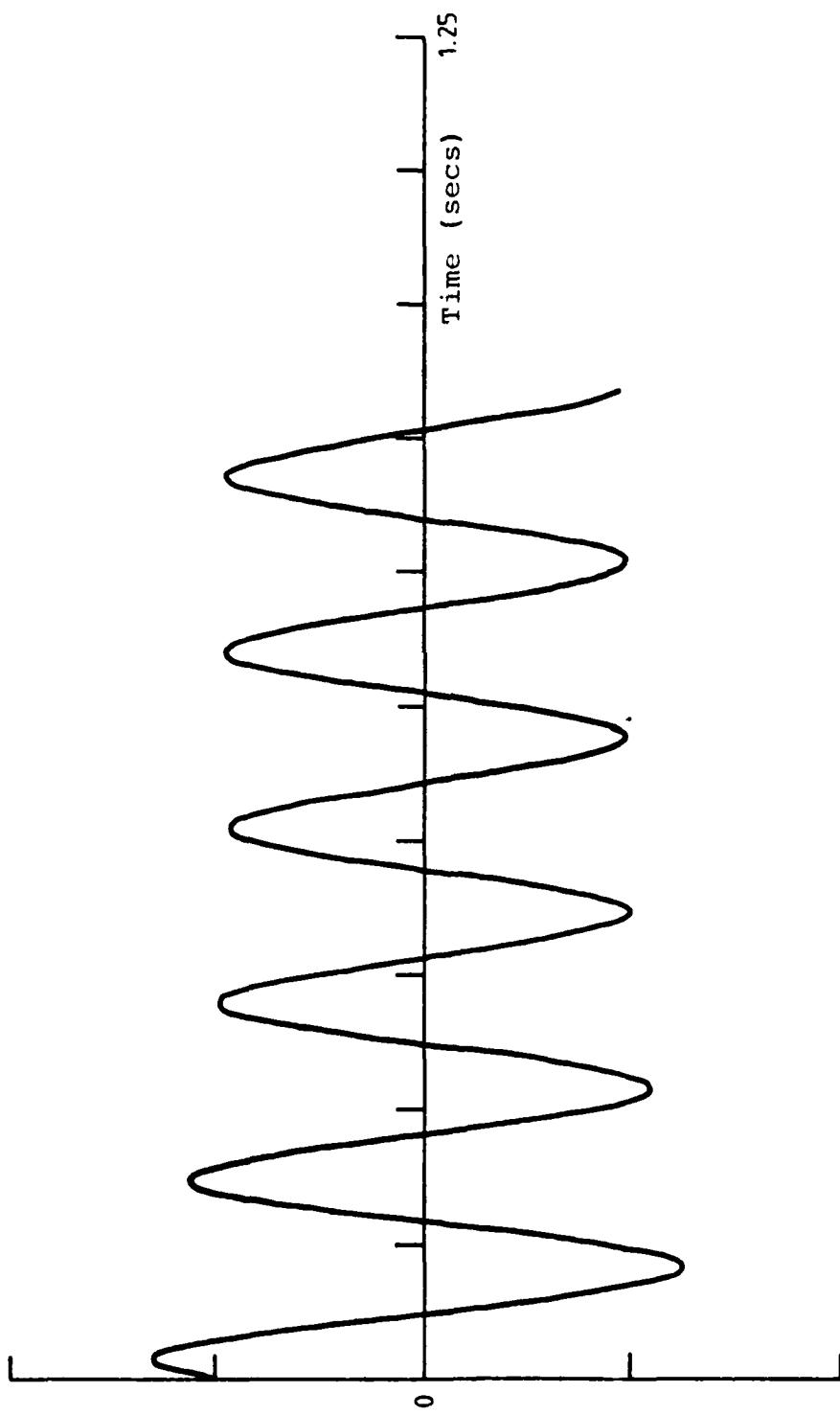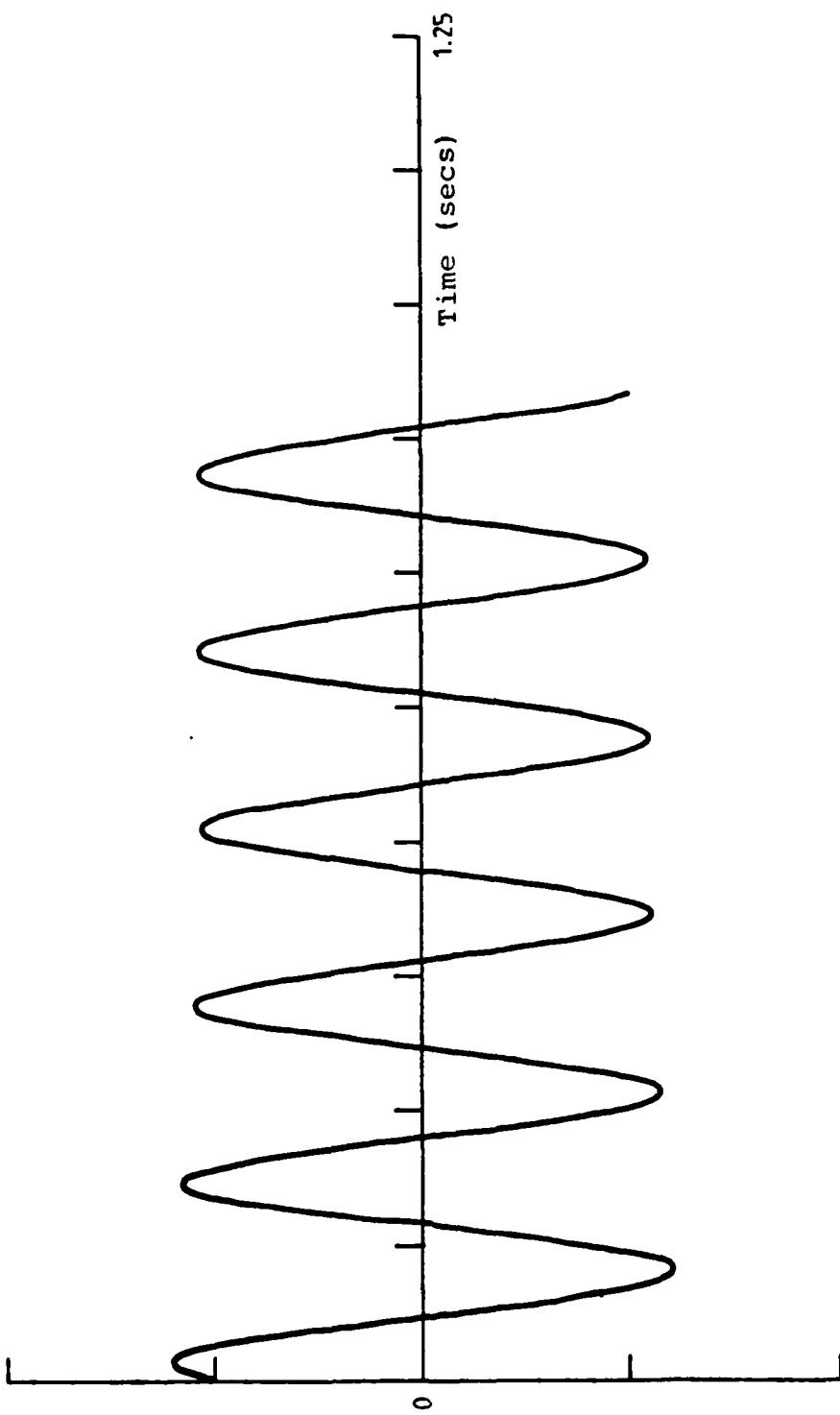
FIG. 8.   DAMPING AT 19m/s

Time (secs)

1.25

0
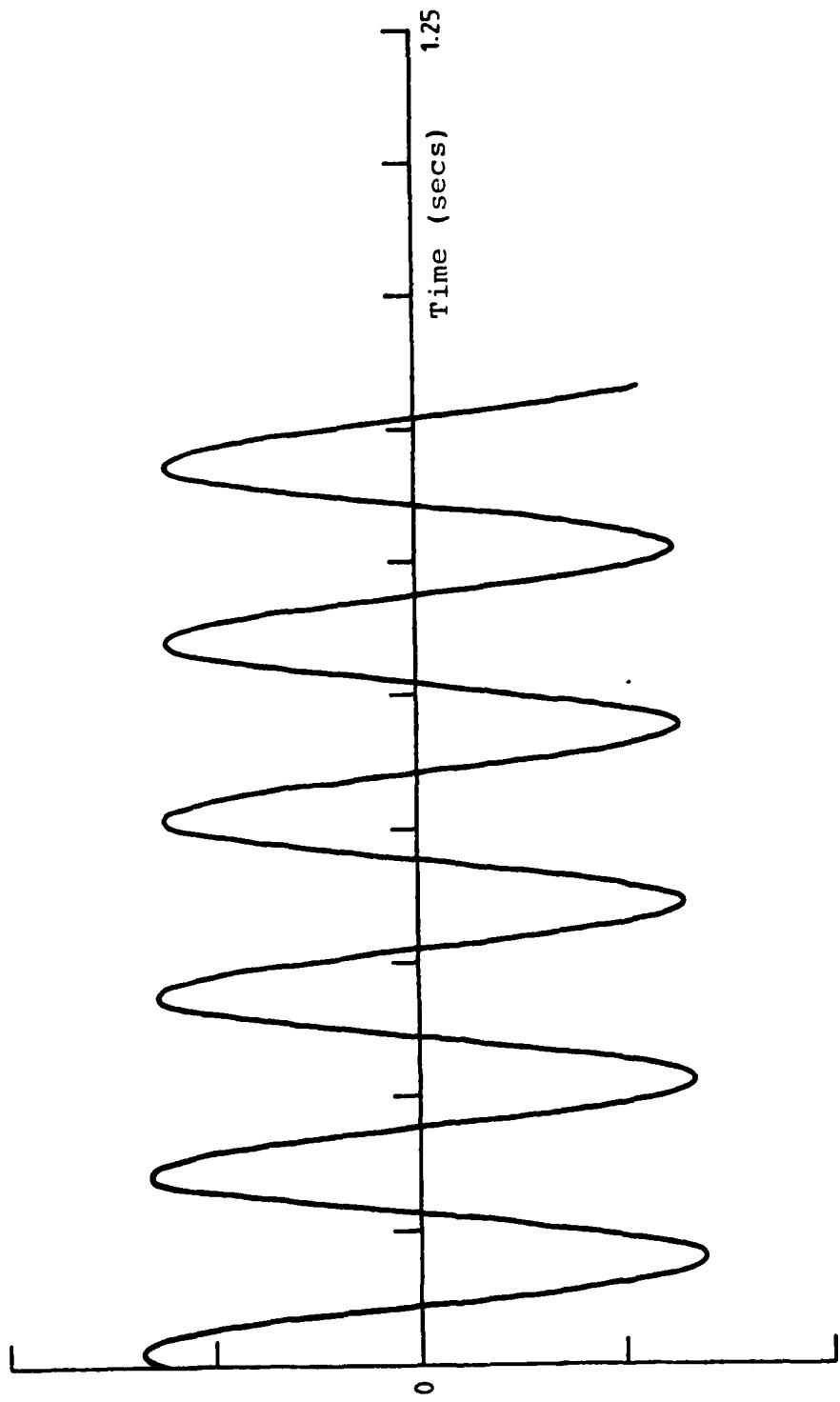
FIG. 9 DAMPING AT 19.5 m/s
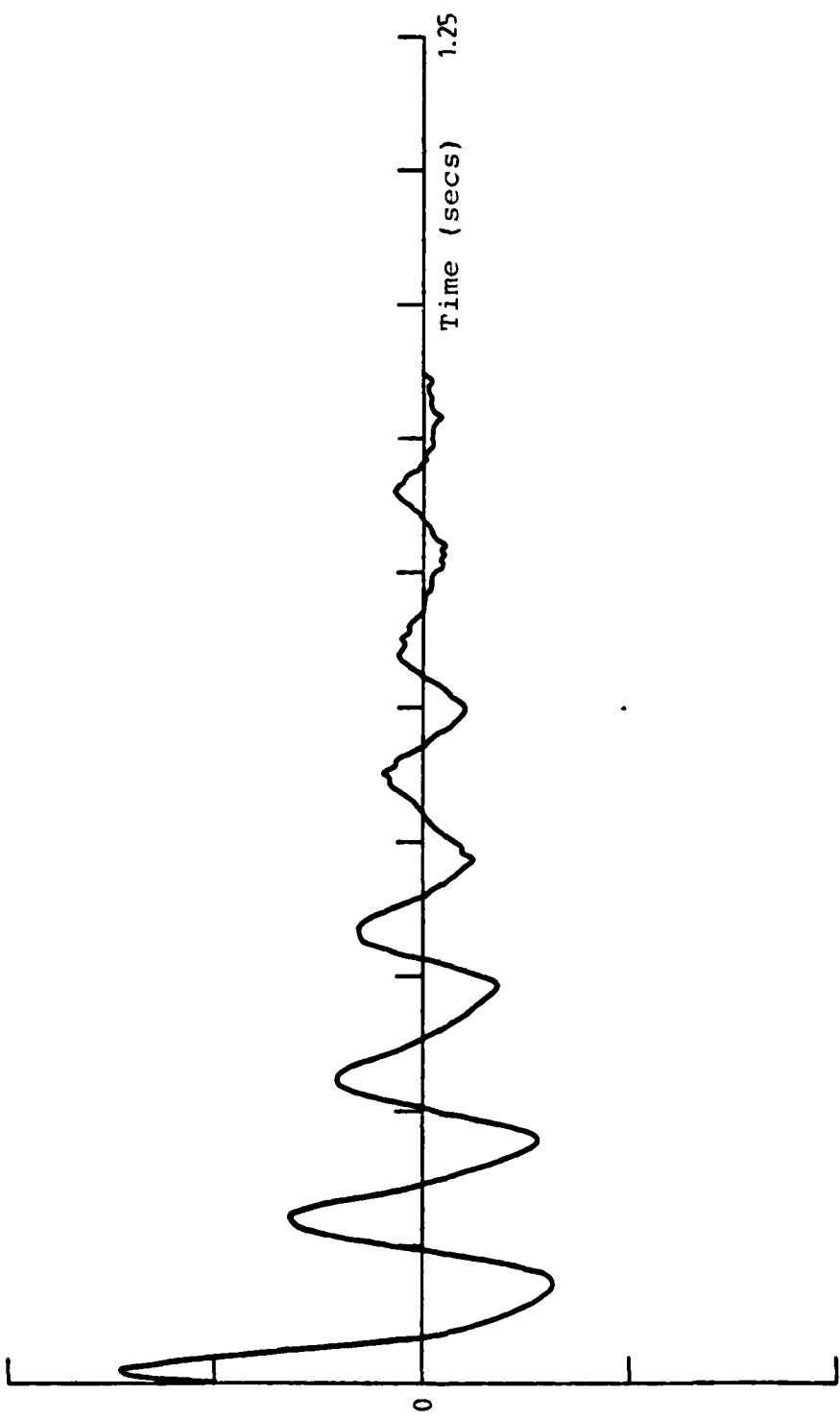
FIG. 10. DAMPING AT 18m/s – WITH CONTROL ON

Time (secs)

1.25

0
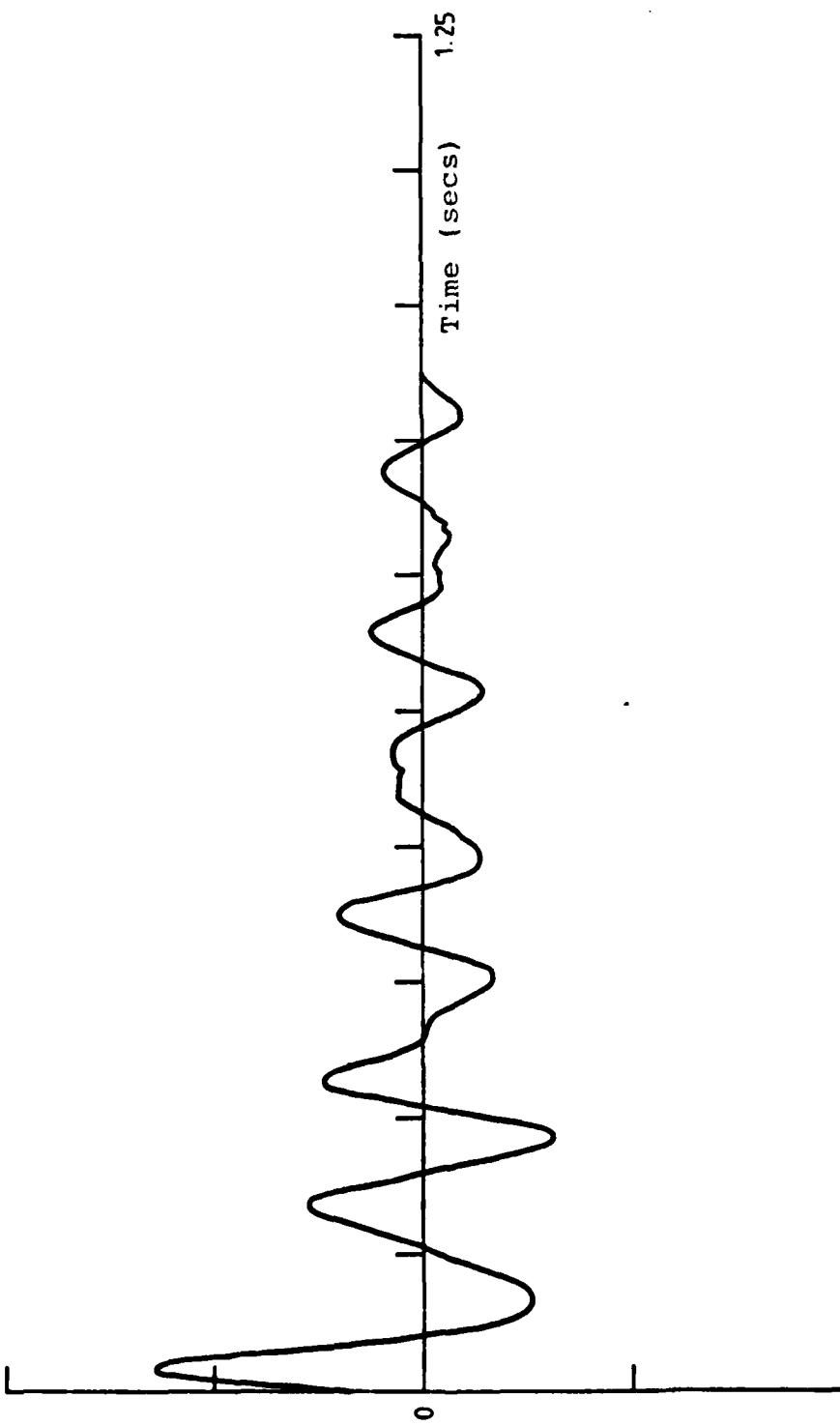
FIG. 11. DAMPING AT 18.5m/s - WITH CONTROL ON
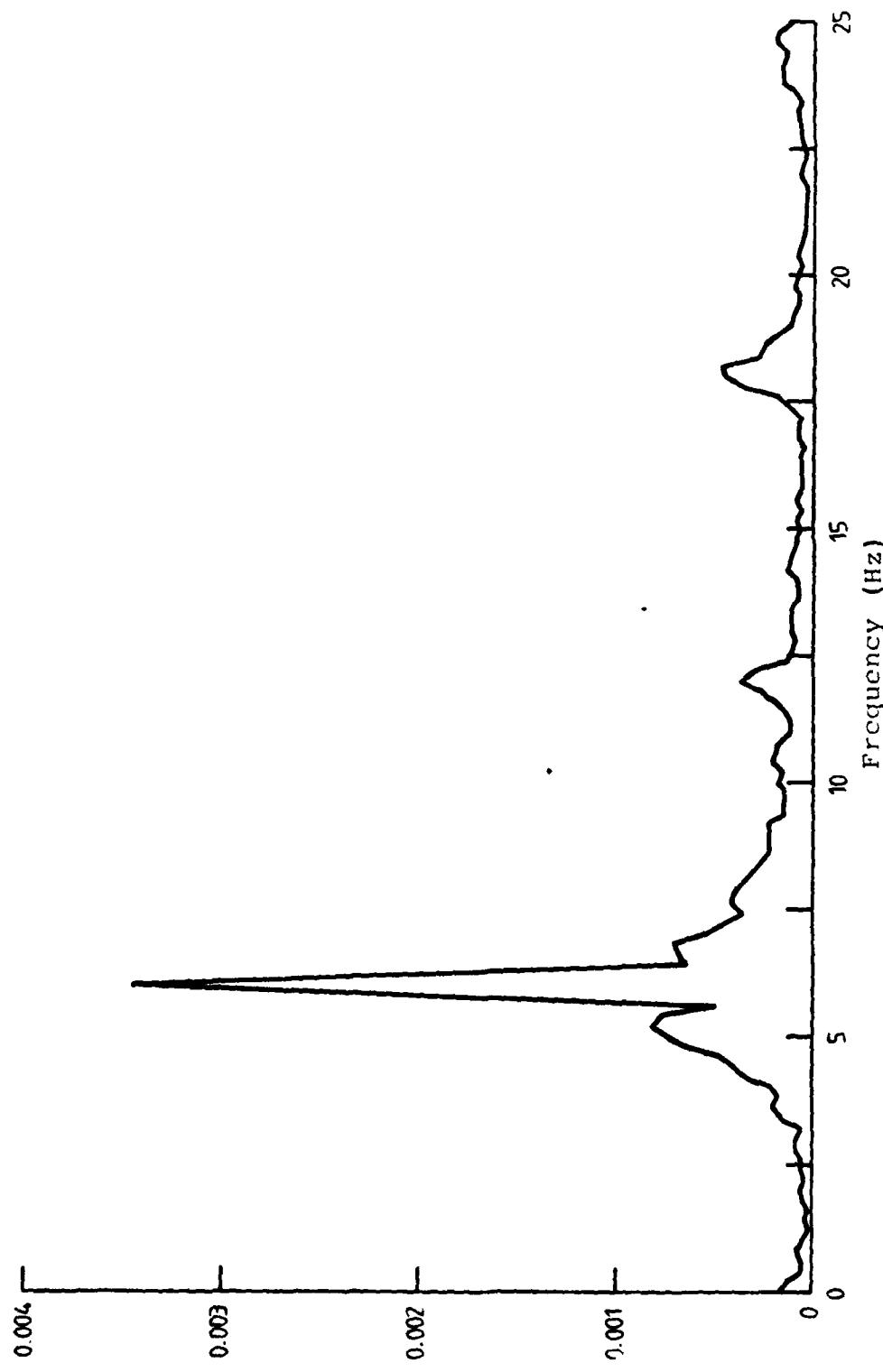
FIG. 12   LOC-L SUP-OFF
VEL-19m/s
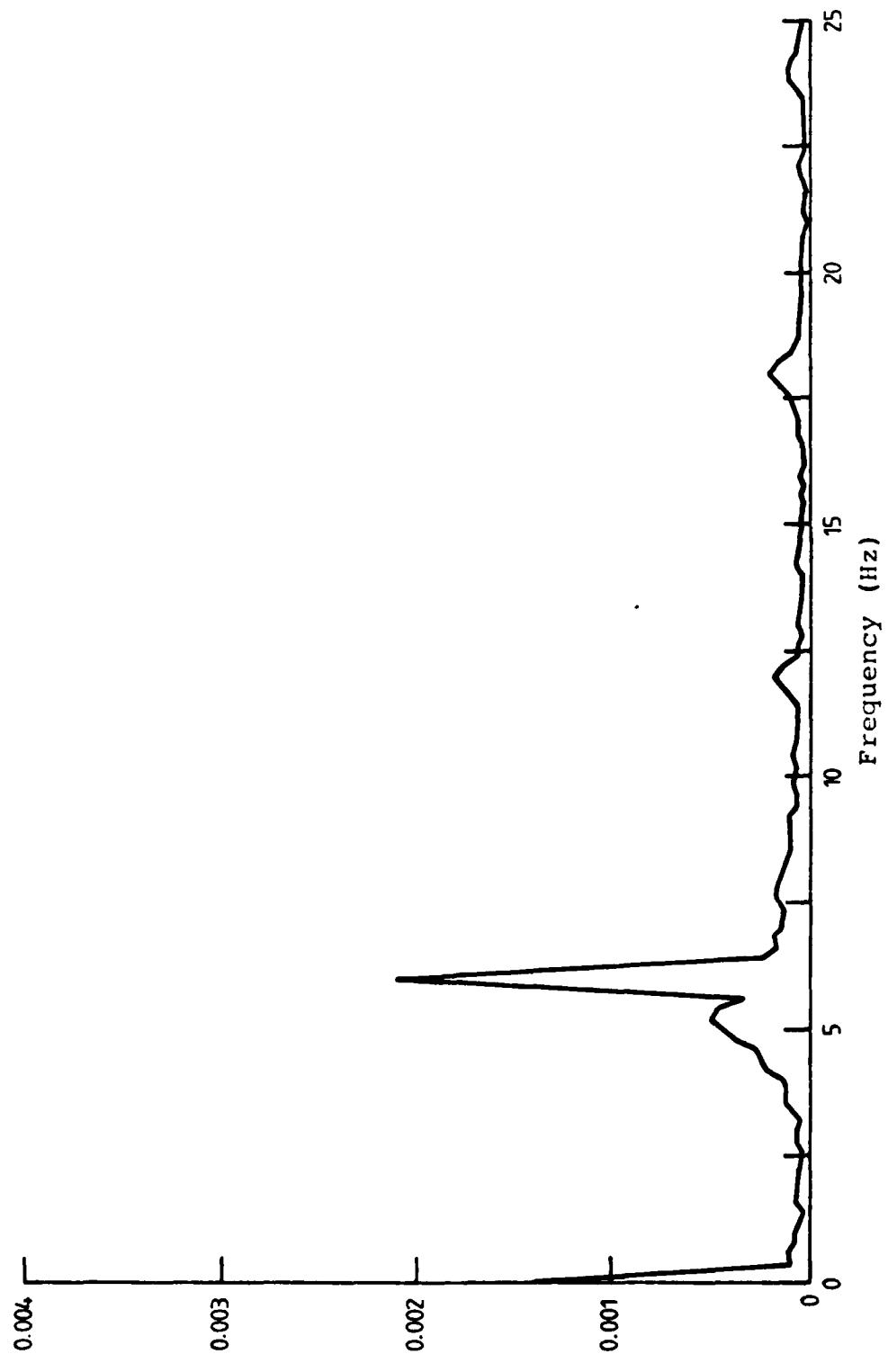
FIG. 13. LOC-M SUP-OFF
VEL-19m/s
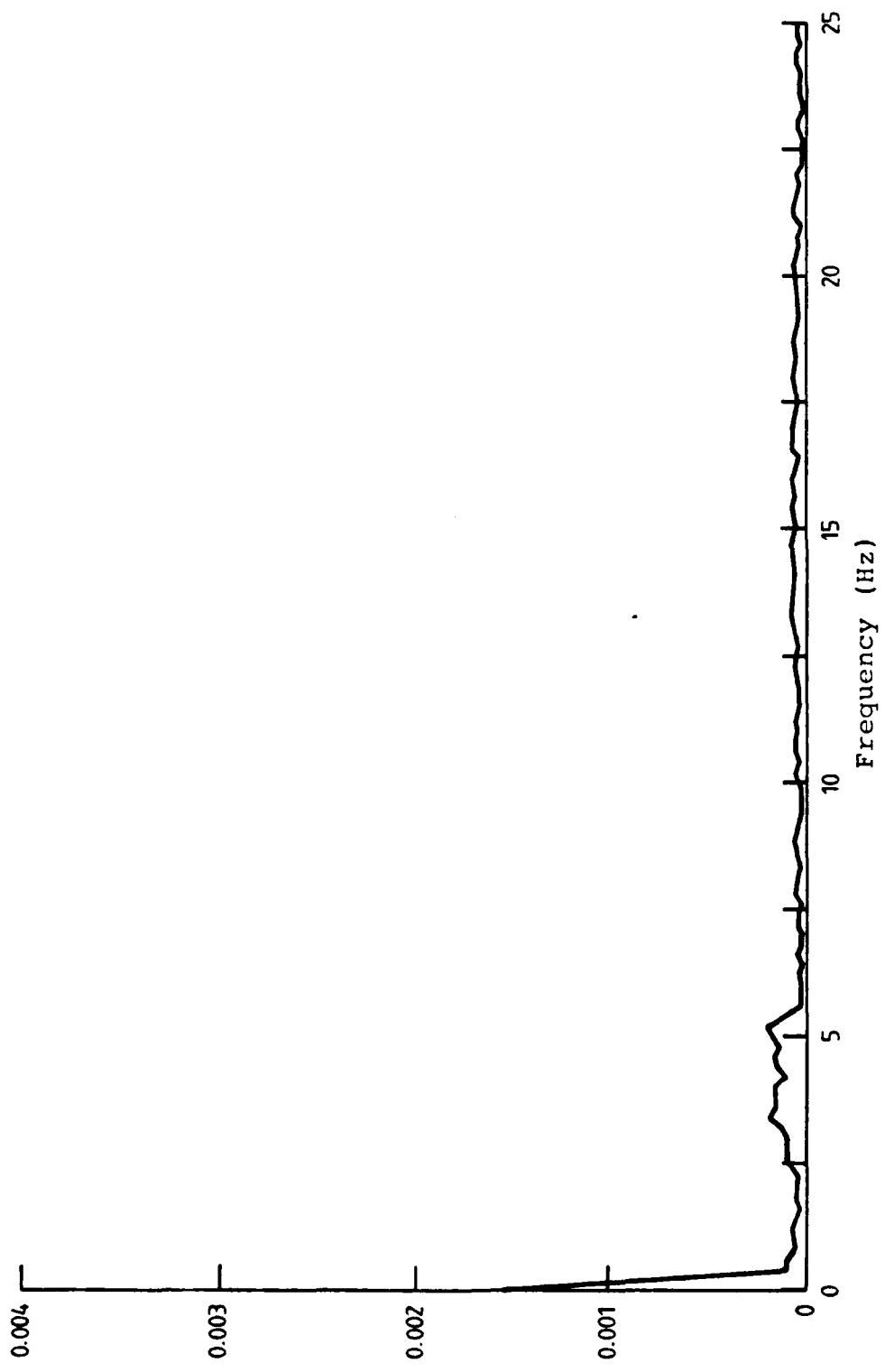
FIG. 14. LOC-M SUP-ON CONT-M 19m/s
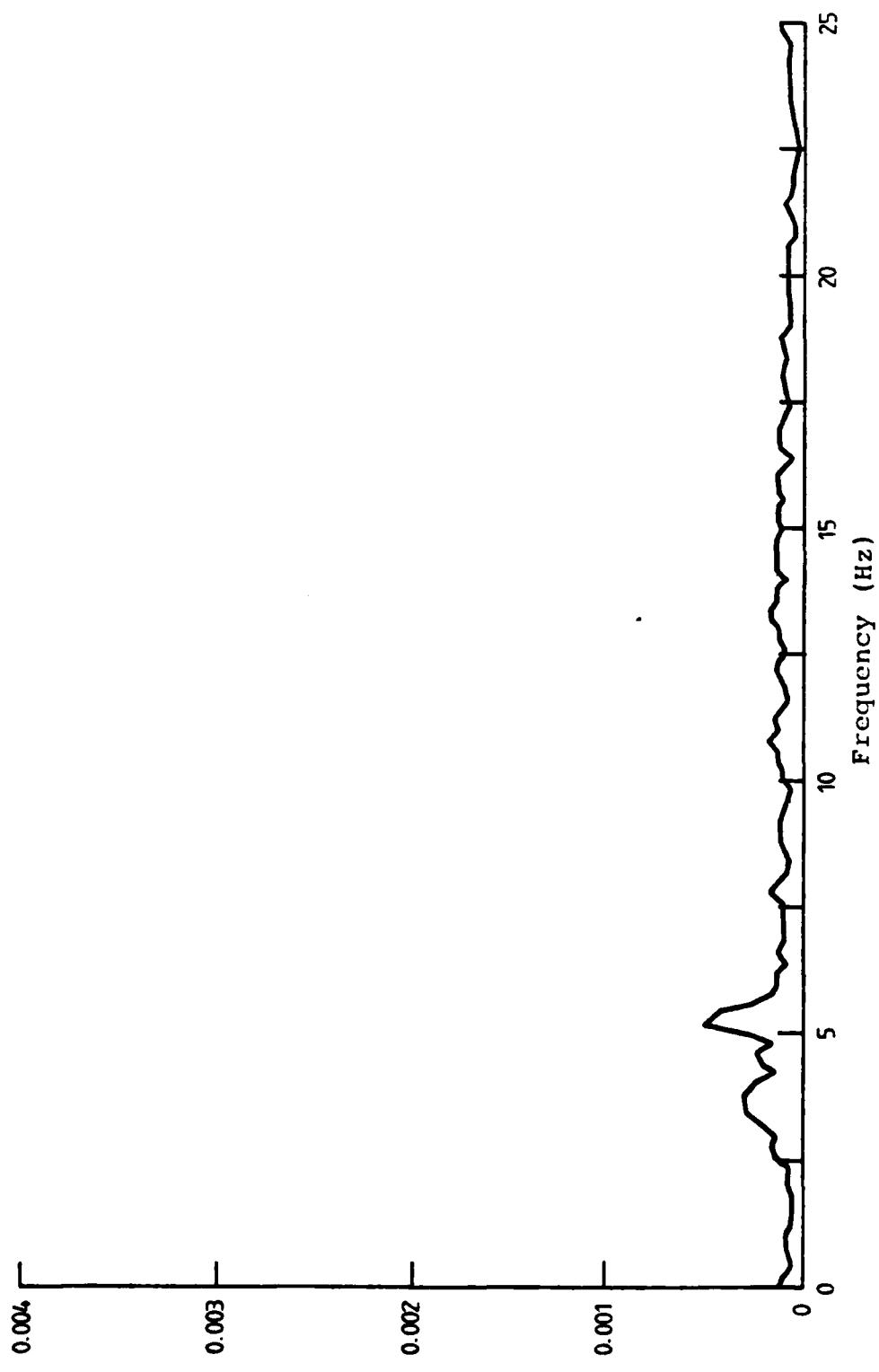
FIG. 15. LOC-L SUP-ON CONT-M 19m/s
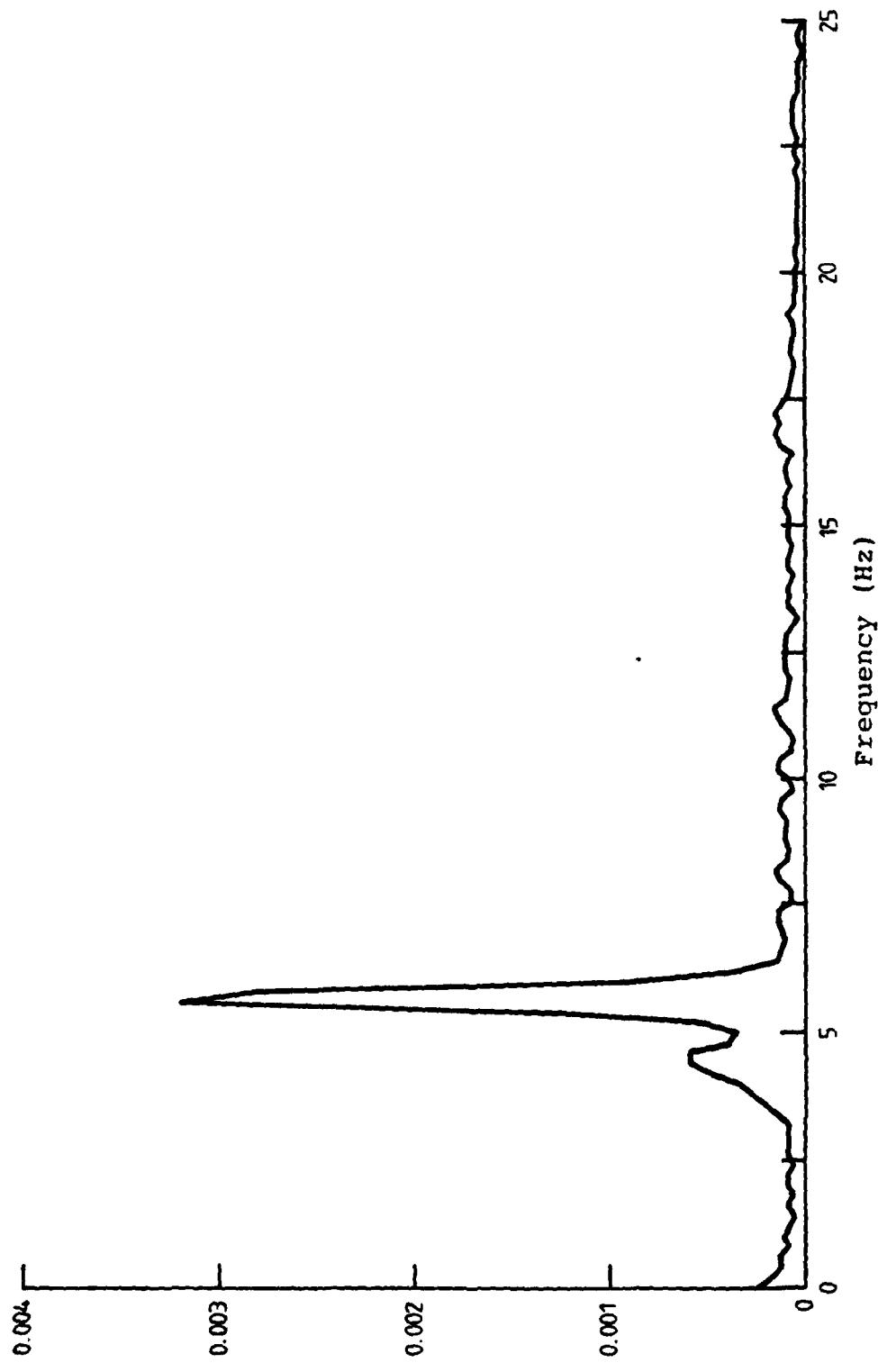
FIG. 16. LOC-M SUP-ON CONT-L 19m/s
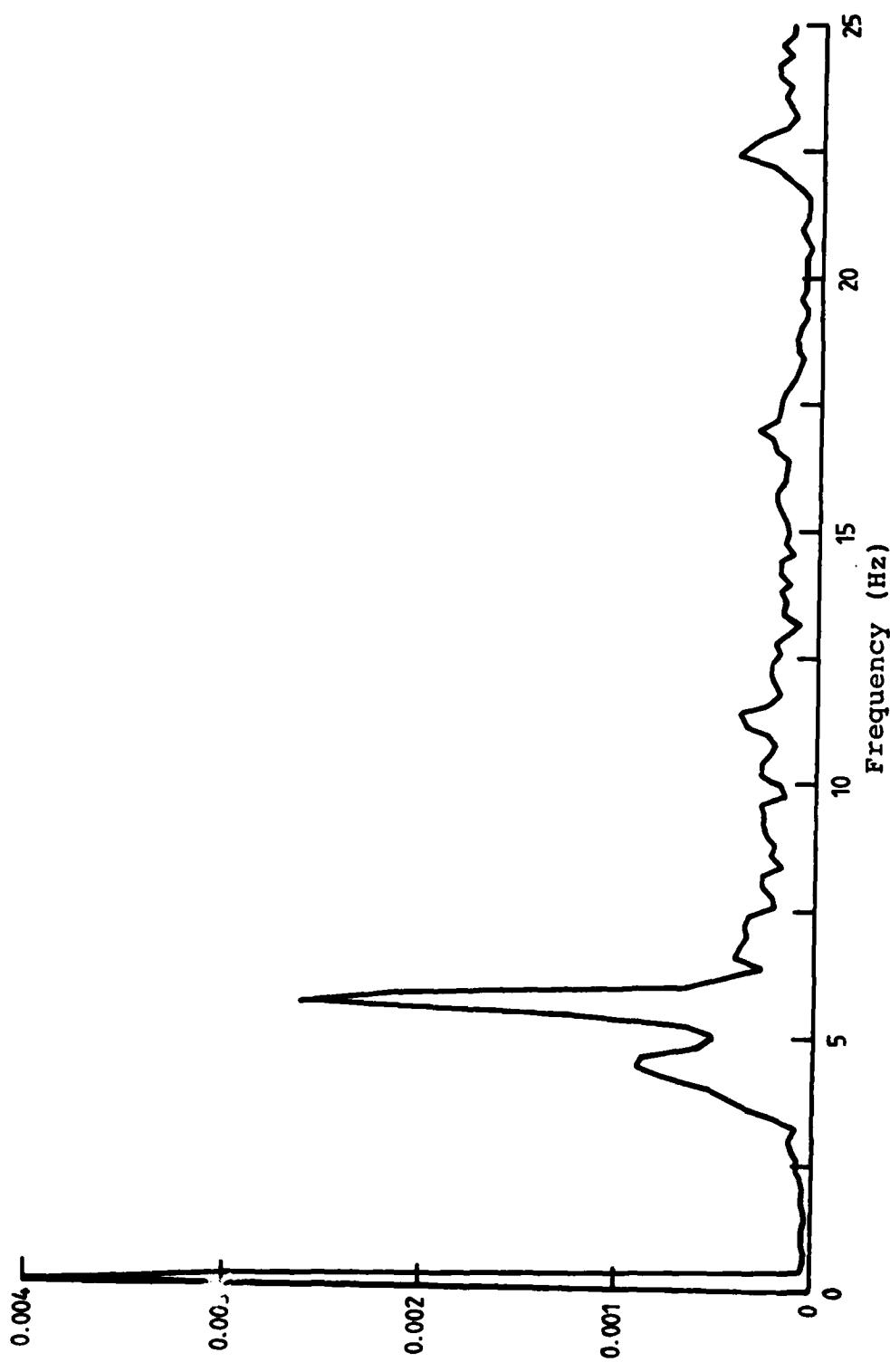
FIG. 17. LOC-L SUP-ON CONT-L 19m/s

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16. Abstract

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